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Archaeological
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of America

THE DISCOVERY, BY PROFESSOR GUSTAVO GIOVANNONI, OF CURVES IN PLAN, CONCAVE TO THE EXTERIOR, IN THE FAÇADE OF THE TEMPLE AT CORI

[PLATES XIV–XXII[1]]

THE object of this paper is to call attention to the recent remarkable observations of curvilinear refinements in the Temple at Cori (PLATE XIV)[2] by Professor Gustavo Giovannoni, Assistant Professor in the Royal School of Engineering Architects at Rome.

The announcement regarding these curves was originally made by Professor Giovannoni before a meeting of the Roman Society of Architects which was held on the 6th of February, 1905. It was first published in the *Annuario* of the Society for that year. The additional facts to be related were then obtained through personal correspondence with Professor Giovannoni, who has also allowed me to describe and publish them. I am advised by his letter of December 8, 1906, that the isolation of the Temple at Cori from adjacent buildings will be shortly undertaken by the Italian Government and that this opportunity will be used for the construction of scaffolds which will enable him to take measurements in detail of the upper portions of the façade. Meantime I quote from an earlier letter, of July 2, 1906, the following information:

"The temple of Hercules at Cori belongs to the late epoch of the Roman Republic and is one of the finest specimens of

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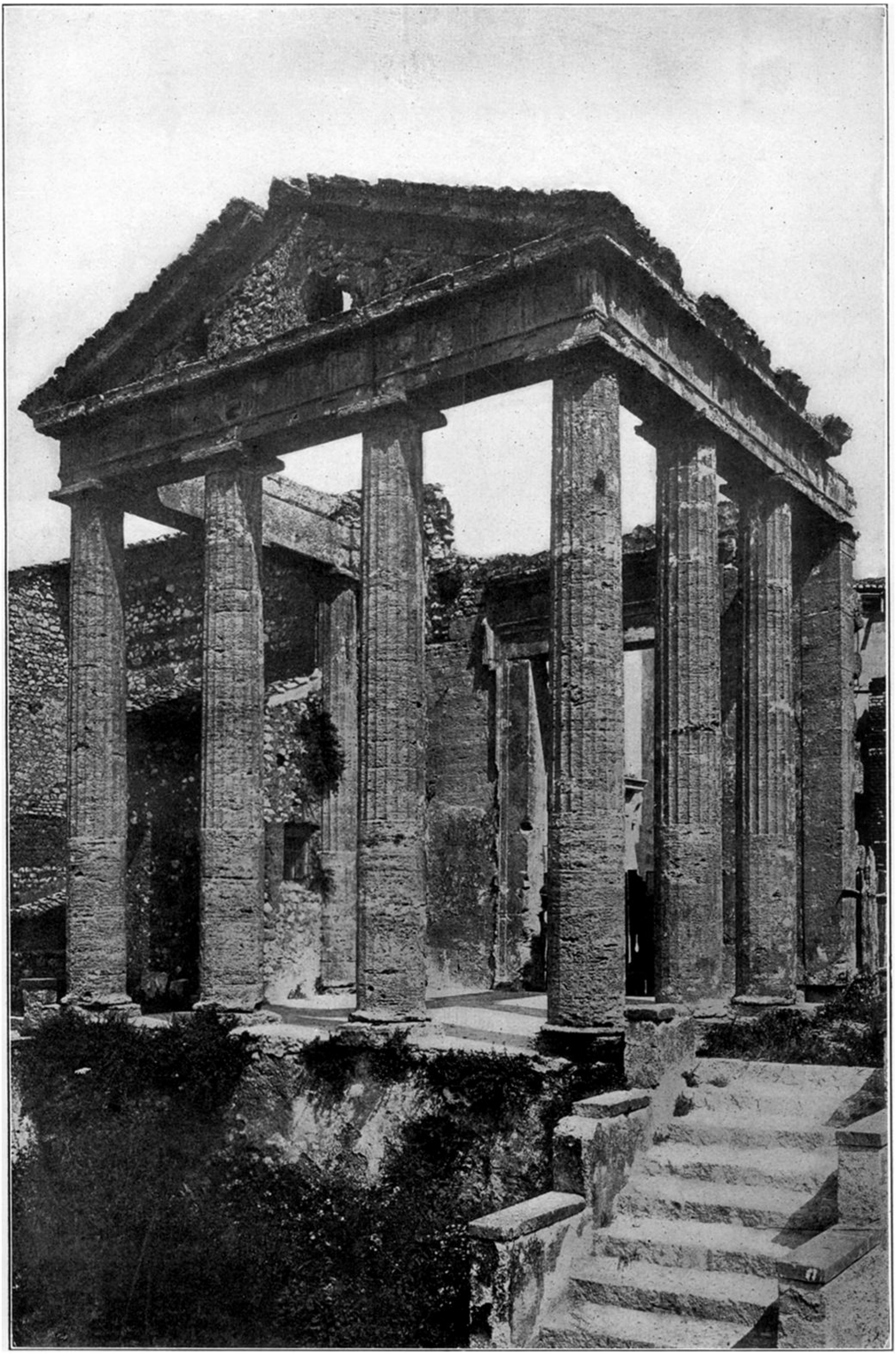
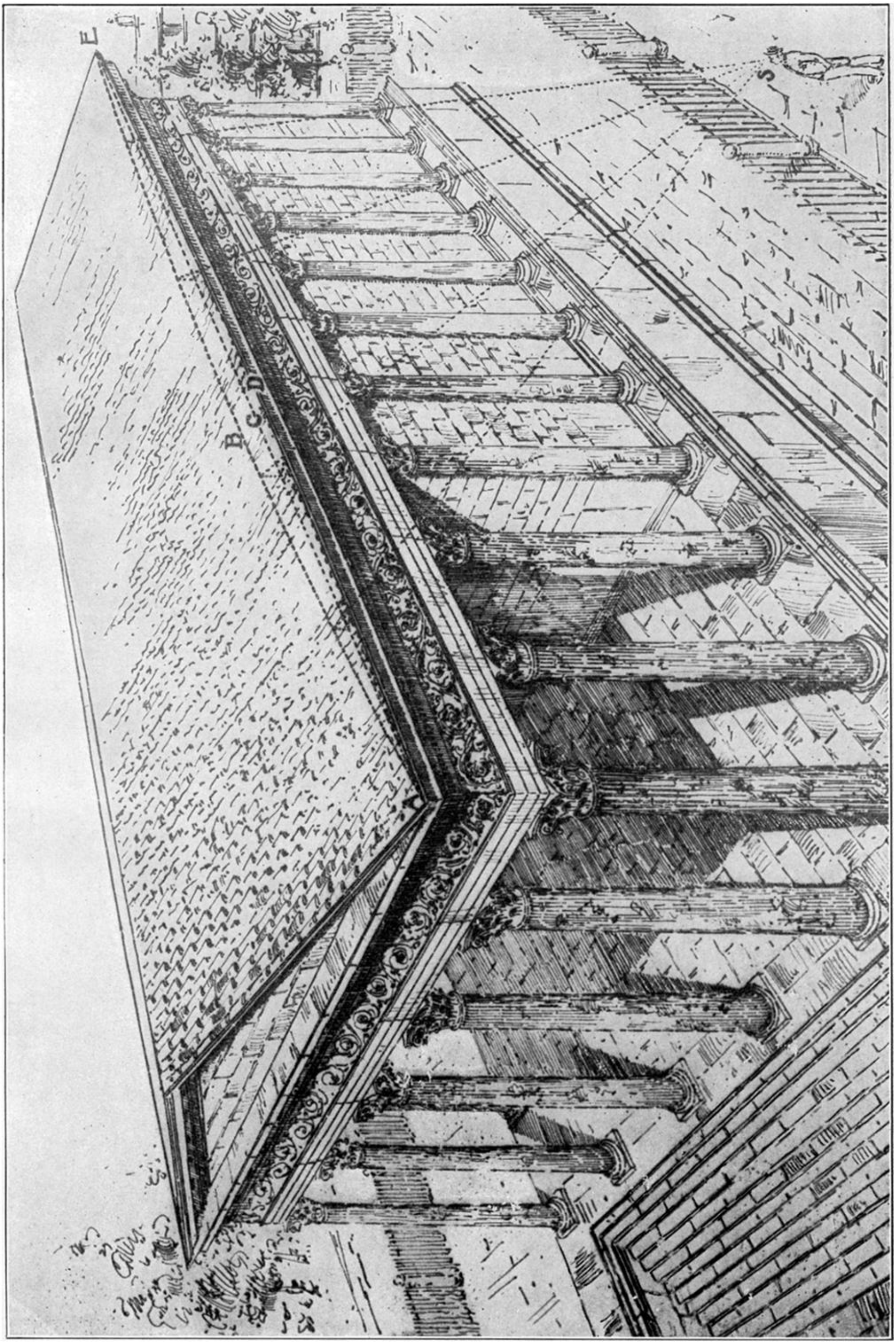
[1] Of the illustrations, PLATES XV and XVII are from drawings by John W. McKecknie, PLATES XVIII–XXI are from photographs of the Brooklyn Museum Survey of 1895, and PLATE XXII from a photograph of the same survey in 1905.

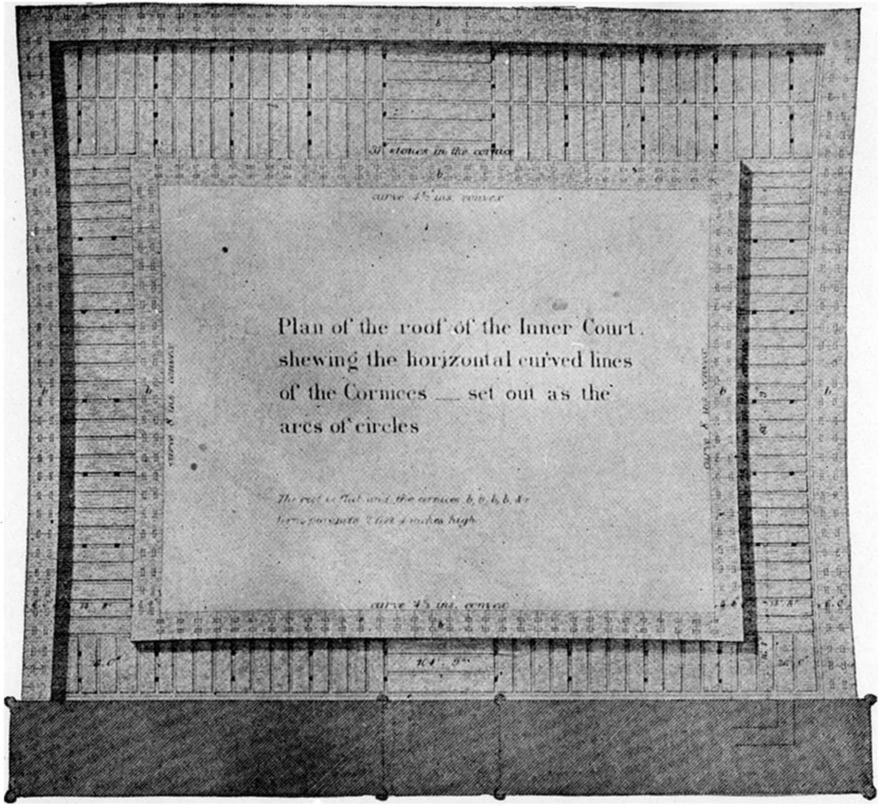
[2] The adjacent buildings interfere with a view of the curve. Its character is shown in PLATE XXI.



THE TEMPLE OF HERCULES AT CORI

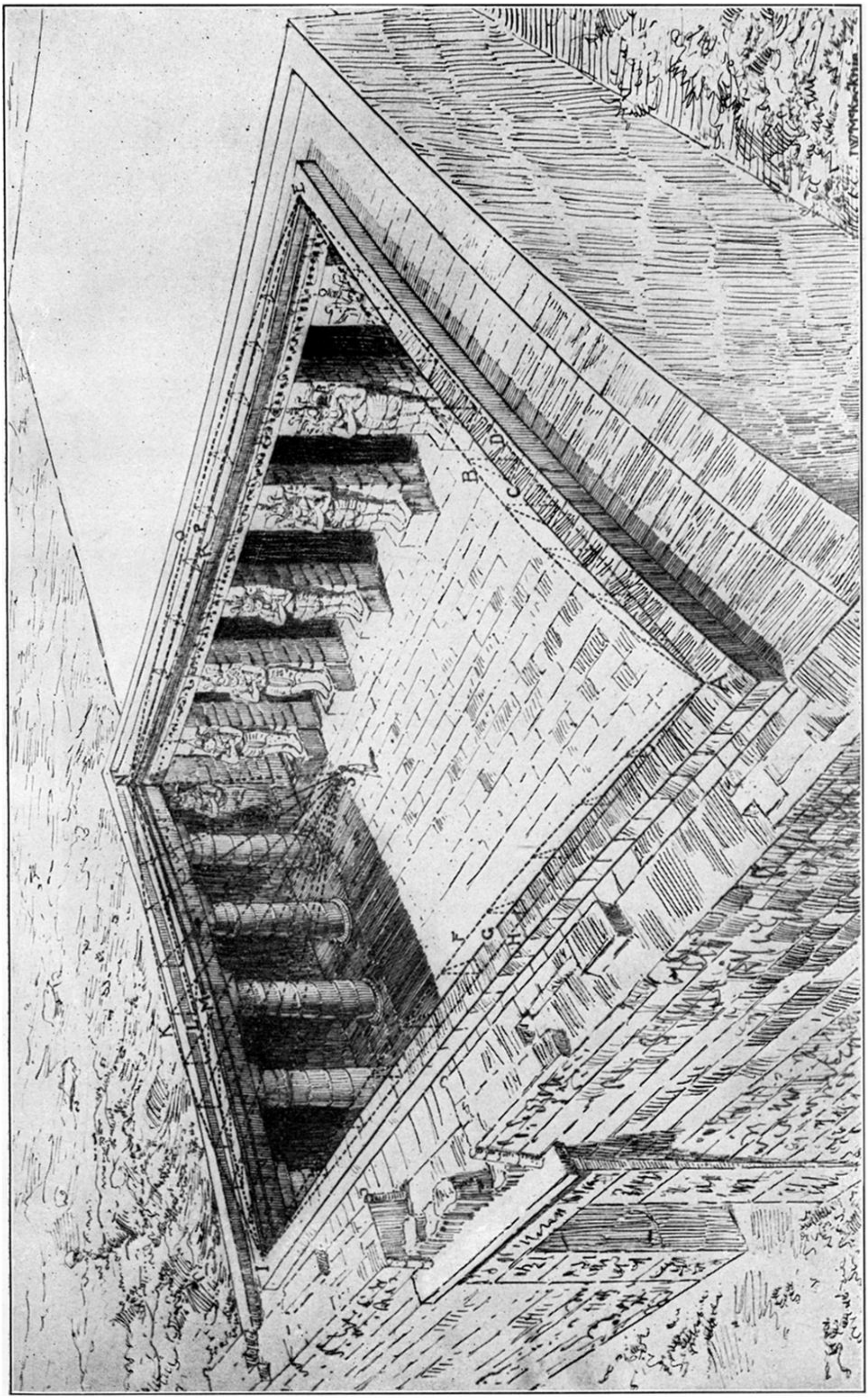


BIRD'S-EYE VIEW OF THE MAISON CARRÉE AT NÎMES

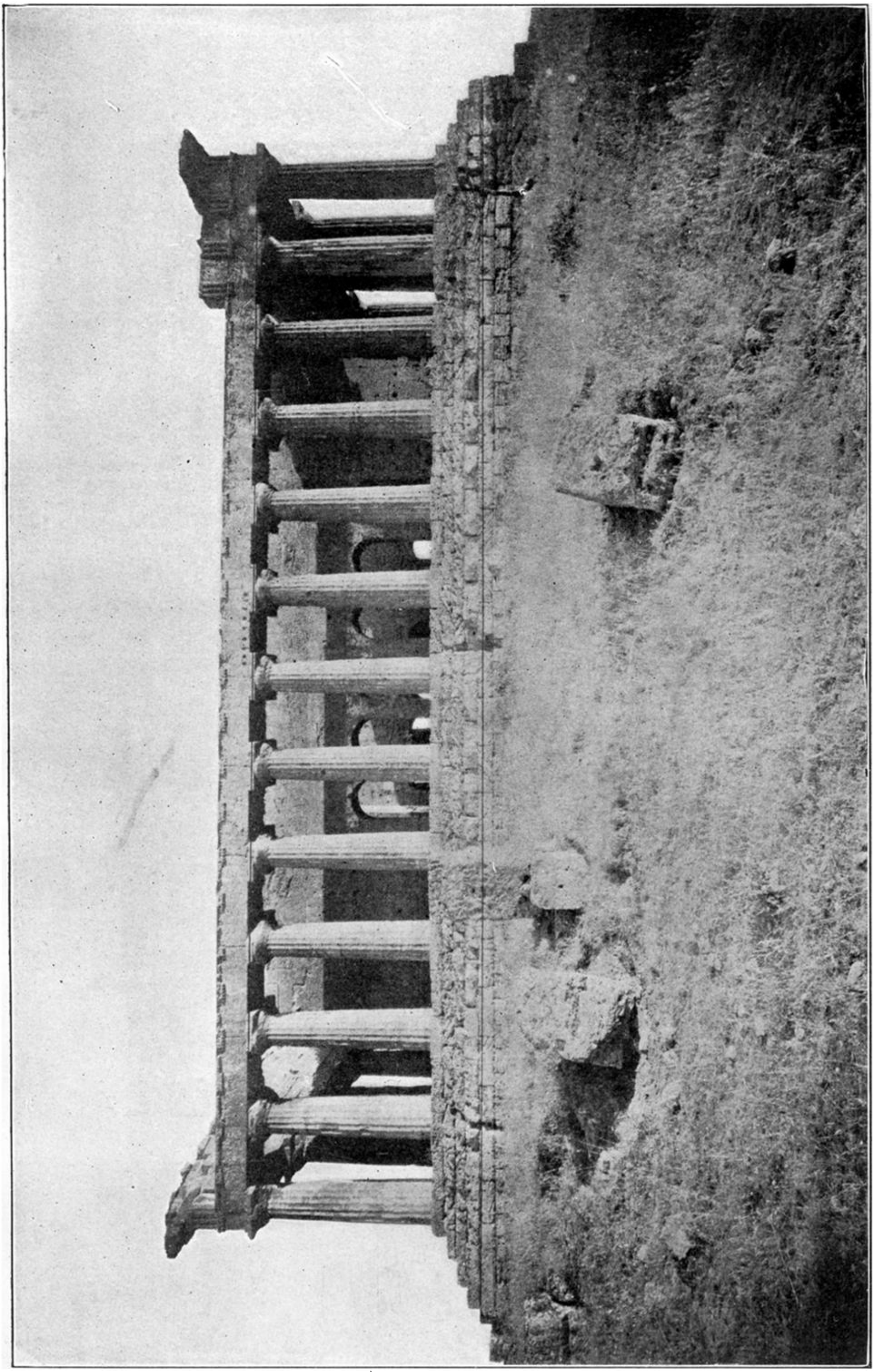

31 stones in the cornice
b
curve 4½ ins. convex
Plan of the roof of the Inner Court. shewing the horizontal curved lines of the Cornices ___ set out as the arcs of circles
The roof is flat and the cornices b, b, b, b, &c form parapets 2 feet 4 inches high
curve 4½ ins. convex
b
104' 9"

PLAN OF THE ROOF OF THE INNER TEMPLE COURT AT MEDINET HABOU, THEBES

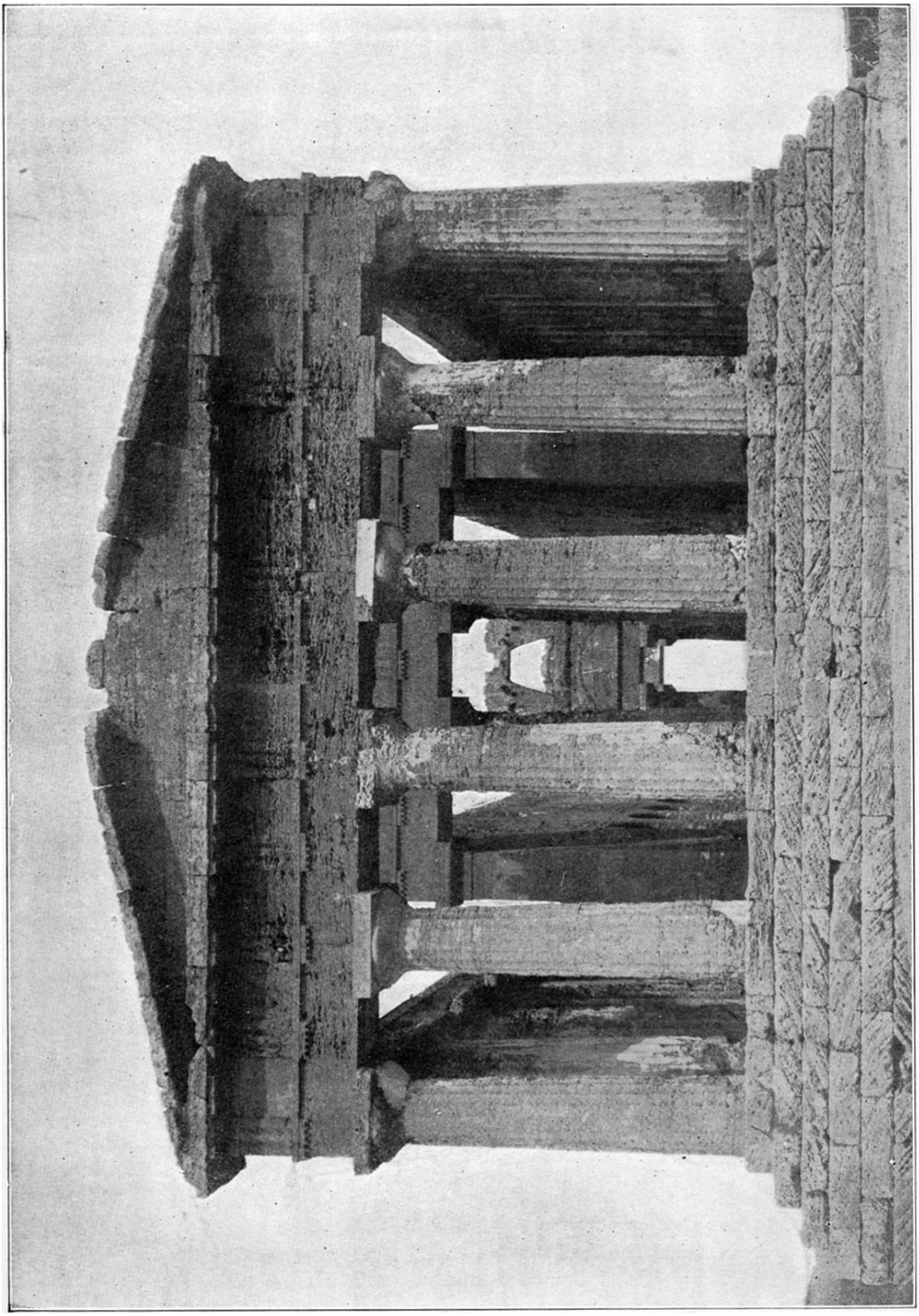
(From Pennethorne, 'Geometry and Optics of Classic Architecture')



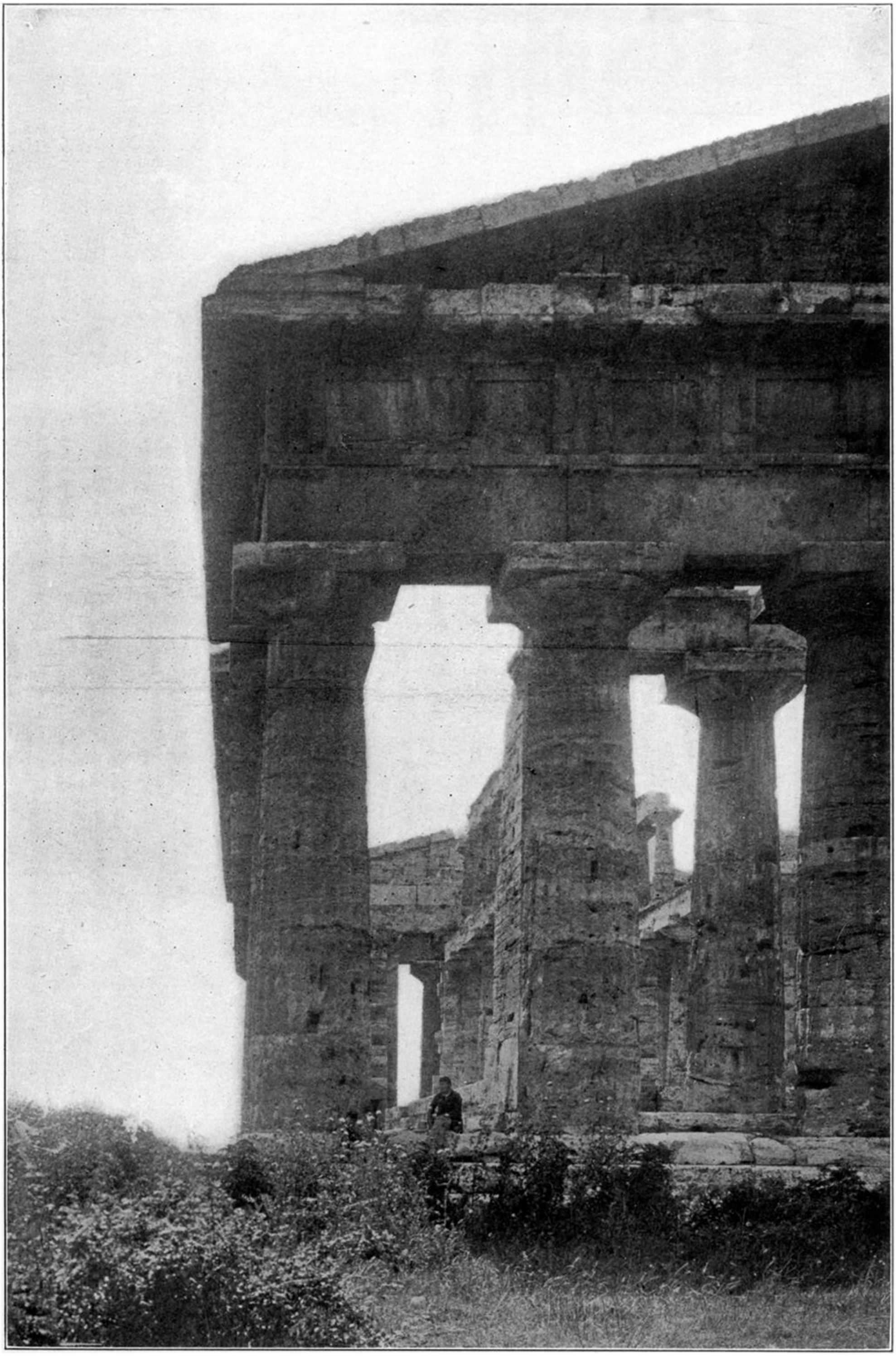
BIRD'S-EYE VIEW OF THE INNER TEMPLE COURT AT MEDINET HABOU, THEBES



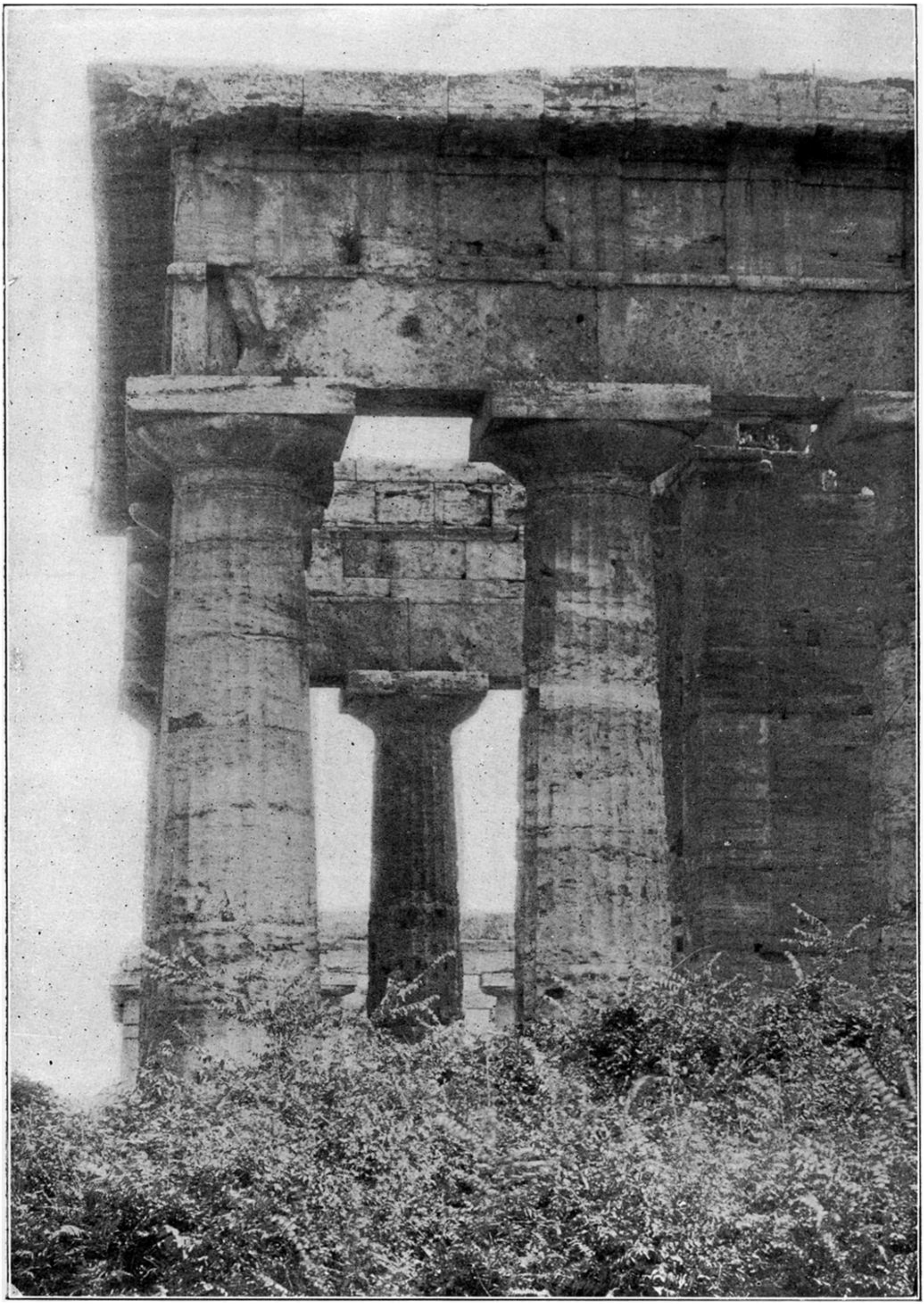
THE TEMPLE OF CONCORD (SO-CALLED) AT GIRGENTI (NORTH SIDE)



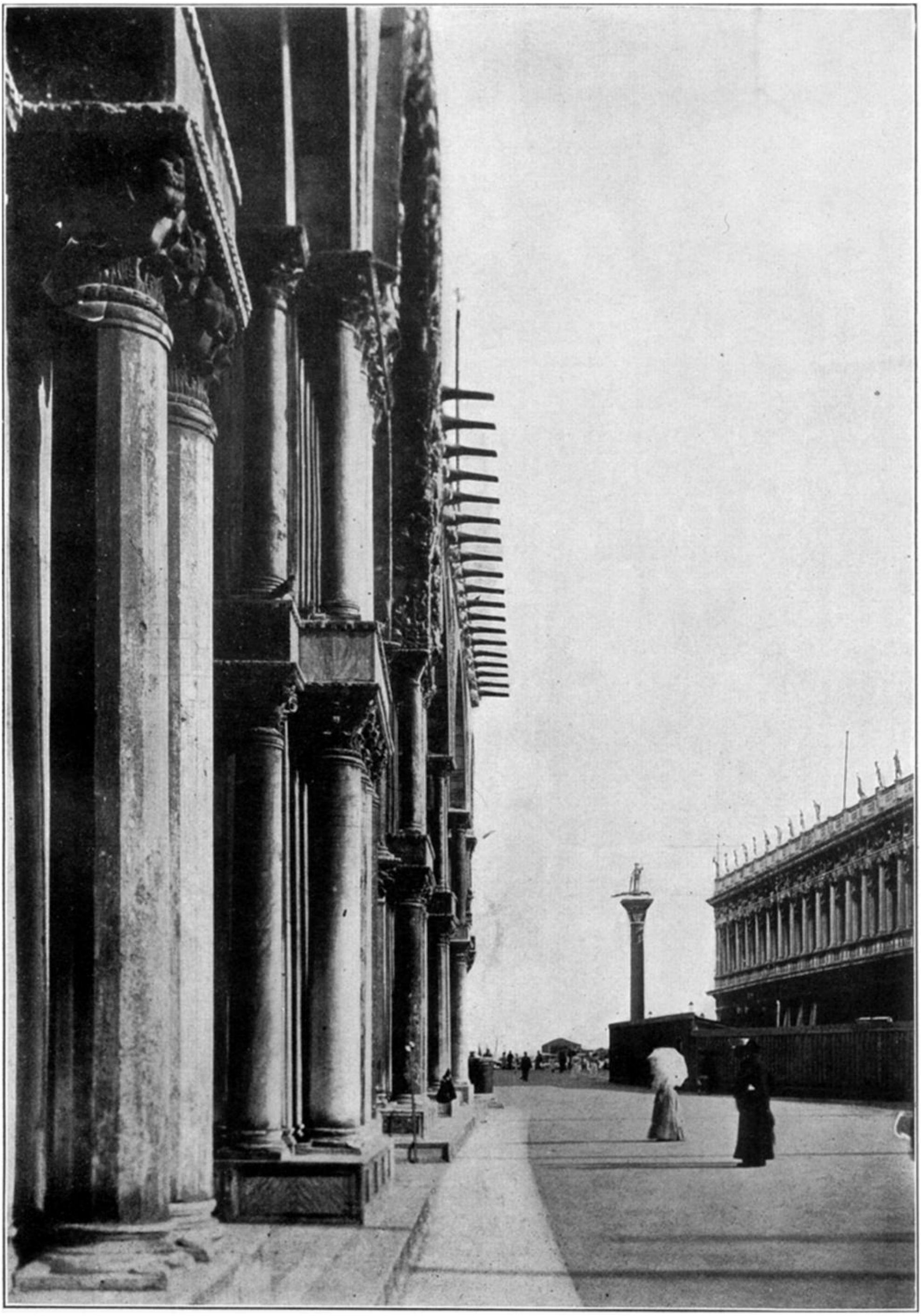
WEST FRONT OF THE TEMPLE OF CONCORD (SO-CALLED) AT GIRGENTI



SOUTH SIDE OF THE TEMPLE OF POSEIDON AT PAESTUM



EAST FRONT OF THE TEMPLE OF POSEIDON AT PAESTUM



FAÇADE OF ST. MARK'S AT VENICE

this period of transition from the Greco-Etruscan style to the Roman. The pronaos and the great door are still in almost perfect preservation and show splendid execution, both from the artistic and from the constructive point of view. . . . The suspicion of accident (in regard to the curves) cannot be entertained.

"No one, however, as far as I am aware, has previously observed or measured the curve of the façade. This curve exists notwithstanding, and is very clearly defined. The concavity (in plan) which is small at the columnar bases, where it measures 10 or 12 cm. deflection, increases to nearly 35 cm. in a length of 7.50 m. at the cornice. The gable follows the same line, and the regularity of the joints gives assurance that neither (original) accident nor subsequent movements have produced this remarkable deflection. There are no curves on the flanks." [1]

As regards the measurements just quoted it is to be observed that the curve of 10–12 cm. quoted for the line of the bases is one of unusually large deflection for the given length of 7.50 m., as compared with other classic curves; and that the curve at the cornice, of 14 inches or 35 cm., is far greater than any curve previously recorded for the ancient monuments, both as regards the actual measurement and still more as regards the relation of other deflections to the greater widths or greater lengths of the given buildings.

Aside from the remarkable amount of the curve, its still more remarkable feature is the concavity in plan, and I need hardly add that this feature constitutes its astounding and novel characteristic. It is further to be noticed that no other Roman temple has been so far announced as showing any curves whatever, with the exception of the Maison Carrée at Nîmes (PLATE XV),[1] which has curves in the cornices of the flanks which are convex to the exterior.[2]

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[1] "Le Temple d'Hercule à Cori appartient à la dernière époque de la République, et il est un des plus beaux spécimens de cette période de transition du style grec-étrusque au romain. Le pronaos et la grande porte sont encore presque entièrement conservés et montrent encore une exécution splendide du côté artistique et constructif. Cette perfection d'ouvrage nous assure que les courbures qui nous pouvons y constater sont vraiment voulues par l'artiste ; ce sont en effet des 'refinements.' La doute qu'il peuve s'agir d'un hasard ne vaut pas ici.

"Personne, cependant, que je sache, n'a remarqué ni mesuré avant moi la courbure du temple. Toutefois cette courbure existe et est très sensible. La concavité, qui est très petite à la base des colonnes, où elle mésure dix ou douze centimêtres de flêche, rejoint presque 35 cm. en horizontale (sur une largeur de m. 7.50) dans la corniche, un peu en retraite du soubassement au milieu. Le fronton aussi suit ce tracé et la régularité des joints nous assure que ni le hasard ni des modifications ultérieures ont produit cette singulière anomalie. Les flancs n'ont pas de courbe."

Aside from the assurances given by Professor Giovannoni as to constructive intention there are two evidences of such intention which speak for themselves, even to those who have not examined the temple; viz., that the curve is found at the bases of the columns and that a concave curved deflection in plan, of the cornice and gable, to the extent of 14 inches, could not have been the result of accidental movements, without the appearance in the connected structure of very visible and palpable dislocations, which must also have visibly affected the supporting columns, either at the angles or near the centre, one or both.

As regards the theories which have been advanced to explain the ancient curves, the discovery of curves at Cori, concave in plan to the exterior, has a revolutionary and far-reaching significance. The optical effect above the level of the eye of a curve concave in plan is that of a curve in elevation (that is, of a curve in a vertical plane) which descends towards the centre. Consequently the explanation which has been so widely quoted and credited, that the ancient curves were intended to correct optical effects of sagging downward, is immediately and decisively thrown out of court in the case of the temple at Cori, for it is exactly an effect of sagging downward which is actually produced by this curve, so far as the upper horizontal lines are concerned.

So conclusive an argument leads us to examine the previous standing of the widely spread impression that the Greek curvilinear refinements were intended universally to correct optical effects of sagging and thus cause the lines to appear straight.

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[1] The upper dotted line suggests the optical effect of the curves in plan, convex to the exterior, which are found on the flanks of this temple.

[2] The constructive existence of these curves has been verified by the official architect of the city of Nîmes and also by his predecessor in the same position. See Smithsonian Reports for 1894 (published in 1896), 'A Discovery of Horizontal Curves in Plan in the Maison Carrée at Nîmes.' Under the same title see also *A.J.A.*, First Series, X, 1895, pp. 1 ff., and *Arch. Rec.*, IV, 1895, No. 4.

This explanation is frequently quoted for the rising curves in elevation, such as are found in the Parthenon and some other Greek temples; and these are the curves which have so far generally received attention. It is true that different curves may have been employed in different ancient buildings for different reasons. It would be establishing a very important fact, if this fact alone were proved by the instance at Cori, but the opportunity is a convenient one to point out that the widely quoted explanation is essentially a popular misapprehension of an entirely different proposition and has never been mentioned by any of the optical experts who have made special publications on the Greek curves.

It is a popular modern prejudice that architectural lines ought to *be* straight. Consequently the suggestion appeals to the popular mind that the Greeks curved their architectural lines in order that they might *appear* straight. Hence, probably, the widely quoted but really mistaken statement that all horizontal architectural lines tend to sag optically at the centre. This impression among architects may be due to the occasional practice of cambering interior flat ceilings or tie beams under a gabled roof, but the problem of optical effects in such interiors has no relation to the general, but mistaken, proposition.

It is an elementary proposition in perspective that horizontal lines above the level of the eye, on near approach, curve downward toward the extremities. This is most easily realized by assuming the position of the spectator to be opposite the centre of a building of such dimensions that the head has to be turned first in one direction and then in the other in order to take in the entire upper line. As the really horizontal upper line to the left of the spectator will descend optically in perspective towards the left, and as the really horizontal upper line to the right of the spectator will descend optically towards the right, it is manifest that the eye in passing from left to right, or from right to left, must see the whole horizontal line optically as a curve descending towards the extremities and highest in the middle. It is equally true that all lines which descend in perspective in a single direction must descend in a curve, optically speaking, because the line which is really straight and horizontal descends in gradually increasing amount according to the distance from the eye. Consequently an actually horizontal straight line which, optically speaking, changes direction from point to point must necessarily change direction, optically speaking, in a curve. It is only the mental knowledge that the line is really straight and horizontal which interferes with the perception that the line is really seen as a curve.

The interference of a mental conviction, based on general positive knowledge, with an actual optical appearance is a well-established fact. This interference of the brain with the true facts of vision has been ably described by Professor Guido Hauck in a publication to be presently quoted. Professor Hauck found that the ability to see the rising curves which optically exist in all horizontal lines above the level of the eye (unless interfered with by other lines) was strongest in women and in the persons whom he calls "Naturmenschen," among whom he includes artists, whereas persons with mathematical and scientific training were frequently unable to see the curves at all. He also found in his own experience a progressive improvement in his ability to distinguish the curves as actually seen by the eye. He also found that optical curves in lines really straight and horizontal could be seen in a line of separated lights illuminating an architectural line at night, when they could not be seen in the same architectural line by daylight. The mental conviction had an effect on the continuous line which it did not have on separate points of artificial light, not visibly connected by the architectural line.[1]

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[1] The mental corrections of optical appearances which are described by Professor Hauck have a curious analogy in the experience of Mr. John W. Beatty, M.A., Director of Fine Arts in the Carnegie Institute at Pittsburg, Pennsylvania. The following extract from his letter to me on this subject is published by his permission: —

"Briefly put, my experience was this: When I first put on glasses for astigmatism, perpendicular lines appeared not parallel, being wide at top; in the size of a newspaper page, about one and one-half inches wider than normal. When I had worn the glasses for several months, lines seemed again parallel. Now, when I take the glasses off, lines are again not parallel, but *wider at the bottom.* Dr. Lippincott's theory was that I had always made mental correction, and lines recorded on the retina out of parallel were made to appear parallel by virtue of mental correction. This seems to be absolutely proven by the history of the case, as above briefly outlined. When I take the glasses off now, I see lines imperfectly at the instant of time, because the brain is not given time to correct the defect. The fact that the greater width is now at the bottom

All these facts assist us to understand why lines which are optically seen as curves are not generally recognized as curves by the everyday human being. They also enable us to understand that the perception of the curves which are optically present in the facts of vision varies according to temperament and according to training. As a matter of fact there is no perspective which is not curvilinear, but as these perspective curves are too delicate to be generally represented in the dimensions of pictures, instruction in perspective, as regards draughtsmen and painters, generally ignores them and hence does not tend to counteract the average human indifference to their existence, which is due to mental correction.

All these points bear on the popular error that there is a natural sagging effect in architectural horizontal lines above the level of the eye; but no optical expert who has made a special study of the Greek curves has ever suggested that such a general sagging effect exists.

Thus the first investigator who made publication on the subject supposed that the Parthenon curves were intended to accent and increase perspective effect, because they develop and accent a form of curve which already exists in the normal optical appearance. This investigator was Hoffer, whose observations, measurements, and publications were made in 1838, and thus anticipated the earliest observations of Penrose by seven years and his publication by thirteen years.

Hoffer's publications were made in the *Wiener Bauzeitung* for 1838, whereas Penrose did not visit Athens till 1845 and did not publish his *Principles of Athenian Architecture* until 1851. The discovery of the Parthenon curves by Pennethorne in 1837 is generally supposed to have preceded the observations of Hoffer, but the publication of Hoffer long preceded that of Pennethorne, which appeared in 1878.

It will be observed that I am not advocating at present the explanation of Hoffer; I am simply pointing out that he was the first expert who made a special publication on the Greek curves and that, so far from suggesting that these curves were

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without glasses, whereas it was at the top with glasses when they were first used, is significant. You will find the reference to my case in the *Archives of Ophthalmology*, Vol. XVIII (1889), p. 18, and more particularly p. 28."

intended to correct an effect of sagging, he supposed that they were intended to enhance and exaggerate a curve of exactly contrary character, and that this curve was mentioned by him as the ordinary optical appearance due to perspective.

The popular impression that the rising curves were intended to correct an effect of sagging, popularly said to be inherent in horizontal lines generally, is probably simply a misapprehension of the theory of Penrose, who never, however, suggested any such appearance in horizontal lines as a general rule. Penrose rested his theory of correction on the optical tendency of a horizontal cornice to curve downward under a gable, because the lower acute angles of the gable tend to appear wider than they actually are; therefore the bottom line appears depressed at the angles, and as the effect of depression gradually decreases according to the distance from the angles, therefore the depressed line appears as a downward curve. According to Penrose the rising curve under the gable was to counteract and correct this effect. But as far as the flanks are concerned Penrose supposed the curves to be explained by the sentiment of beauty and the appearance of strength, but to have been originally suggested by the application of the curve as an optical correction under the gable. Thus we are led next to ascertain the present standing of the gable theory of Penrose, which appears to be the original form of the debated popular impression, although it is really a wholly distinct proposition.

This leads us to consider what other authorities later than Penrose have had to say about his gable theory. This gable theory has never, to my knowledge, been accepted or even favorably mentioned by any German optical authority. On the contrary, it has been vigorously and successfully contested by the two greatest German authorities who have subsequently discussed the curves from the standpoint of the expert in optics. First, Thiersch[1] added to a variety of solid arguments one which must appeal to every understanding, whether that of an expert or not. The argument is, namely, this: If Penrose was correct in believing that the curves of the entablature and cornice at the ends of the temple were intended as an optical correction under the gable, and to make the lines appear straight, how does it then happen that the stylobate is curved also, for which no such gable effect exists? This argument is unanswerable. Its only weakness is that it is so simple, so conclusive, and must be so briefly stated, that it falls short of effect from sheer simplicity. It is not necessary here to rehearse the special theory of Thiersch, who thus and otherwise contested the gable theory of Penrose, because it has also been thrown out of court by two subsequent publications. One of these publications was that of Guido Hauck.[1]

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[1] 'Optische Täuschungen auf dem Gebiete der Architectur,' *Zeitschrift für Bauwesen*, XXIII, Berlin, 1873.

Although Hauck abandoned the new explanation of Thiersch, he approved, rehearsed, and elaborated the arguments which led Thiersch to reject the theory of Penrose, especially dwelling on the point that the stylobate need not have been curved if the object of the curve was to correct an apparent deflection under the gable. Both Thiersch and Hauck also urge the sensible view that to consider the curves of the entablature on the flanks of a temple as purely an afterthought is a far-fetched and wholly unsupported hypothesis. Let it be also observed that the theories of Thiersch and Hauck which proposed to supplant the theory of Penrose make no reference to a general sagging effect in horizontal lines, and Hauck expressly develops the fact that horizontal lines above the level of the eye tend normally to curve downward toward the extremities instead of curving upward toward the extremities, as they would if they had a sagging effect. Thiersch alludes to the same fact as holding for near approach.

The publication of Hauck is undoubtedly the most valuable and far-reaching contribution to the optics of rising curves in elevation which has ever been made. But as an explanation of the subject of curvilinear refinements, viewed as a whole, it has also been thrown out of court, and therefore needs no detailed description. It is sufficient to say that it is based, like the theory of Thiersch, on the form of the Greek temple and on the idea that the curves were invented by the Greeks and that these curves were always rising curves in elevation.

Neither Thiersch nor Hauck was acquainted with the *curves*

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[1] Dr. Guido Hauck, *Die Subjective Perspektive und die Horizontalen Curvaturen des Dorischen Styls.* Stuttgart, Conrad Wittwer, 1879.

in plan of the cornice, convex to the centre of the court, in the second Temple Court of Medinet Habou (PLATE XVI). These curves were discovered by Pennethorne in 1832, but he did not publish them until 1878. This was only a year before Hauck's publication, and the Egyptian curves were still unknown to Hauck in 1879. If the gable theory of Penrose required a final death blow, it would be furnished by the curves in plan of the second Temple Court of Medinet Habou, where there are naturally no gables. But the curves in plan at Medinet Habou also fall outside of the special theories of both Thiersch and Hauck, and this is why I have not explained the latter's view. It will not be overlooked, however, that the optical effect in the cornices at Medinet Habou is that of a rising curve in a vertical plane. At the angle of 45 degrees the spectator has the effect of a rising curve in elevation of an amount equal to that of the curve in plan (PLATE XVII).[1] At points farther removed the curve appears less. At nearer points the effect is greater and increases enormously on close approach. Thus on close approach the normal perspective curve is much exaggerated.[2]

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[1] The upper dotted lines show the optical effect of the curves in plan.

[2] The theory of Thiersch, briefly stated, starts from the illusion which tends to affect the appearance of two lines meeting at an angle. These effects were cited by Penrose for acute angles, as calling for a correction under the gable. Thiersch, however, points out that, whereas acute angles appear larger than they really are, obtuse angles appear smaller. His arguments contend that the direction of Vitruvius regarding the construction of the curves was limited to those temples which stand on an elevated platform above the level of the eye. Thus the Parthenon, as seen by a spectator *looking toward one of the angles*, would exhibit obtuse angles both in the stylobate and in the entablature (with the apex of the angle turned toward the spectator). These angles would appear smaller than they are, and as this effect decreases with the distance from the angle, the lines would appear to curve downward away from the angle. This effect would be corrected by a rising curve in elevation. Hauck contested this explanation on the ground that the optical deflection of the obtuse angle was so inconsiderable that a correction would not be needed, but more particularly because such a correction would, in any circumstance, only be needed for the spectator looking toward the angle of the building, and would not be needed in views facing the front or sides. Hauck based his own theory on the fact that the intercolumniations of the Parthenon are smaller at the angles, by about two feet, in order to admit of placing the corner triglyphs at the angles of the building, instead of placing them over the centre of the abacus, where they normally appear. This diminution of spacing gives an increase of perspective from the

Still another argument against the gable theory of Penrose is furnished by the Brooklyn Museum surveys of 1895. The point of view facing any side of the temple from positions nearly opposite the centre. Hence according to Hauck, if the perspective rising curves in elevation were not also correspondingly increased, the perspective effect of the columns would be out of harmony with the perspective effect of the horizontal lines. Thus Hauck in a sense returned to the explanation of Hoffer. For although he held that perspective exaggeration, for its own sake, would not have been in line with Greek feeling, he also held that this perspective exaggeration was properly sought in view of the contradictory effects otherwise produced by the necessary narrowing of the angle intercolumniations.

As the title of Professor Hauck's monograph indicates, he supposed that the Greek curves were confined to the Doric style, in which style alone the angle intercolumniations were reduced, in order to allow the triglyphs to be placed at the angles of the temple. Since that date the discovery of curves in the Ionic temple at Pergamon would have vitiated his theory, but it is also wholly unavailable for the curves at Medinet Habou. So far as the theory of Thiersch is concerned the openings of the obtuse angles in the interior of the court at Medinet Habou are turned toward the spectator, not away from him (as in the exterior of a Greek temple). The angle illusion, if any were produced, would, therefore, be a rising curve in elevation and would thus need no correction.

Although the theories of Thiersch and Hauck are no longer tenable, their publications still have great interest and importance as critiques of the theory of Penrose, and otherwise.

It ought perhaps to be added that the theory of Thiersch is the only one which has ever even been offered, to explain the account of Vitruvius. Although the explanation of Vitruvius has been otherwise universally discarded, or (more generally) ignored, it ought to be possible to determine his reasons, even if his explanation be not correct. Vitruvius directs that the stylobate of the temple shall be built with a rising curve in elevation, lest it appear "alveolated" (like the bed of a channel) and the curves of the entablature are considered as a mere outcome or logical sequence of the stylobate curve. Thiersch moves from the fact that Vitruvius is speaking of temples resting on a *podium*, that is, above the level of the eye of the exterior spectator, and that the effect of sagging from the exterior point of view was to be counteracted by the curve. I will venture to suggest that Vitruvius is speaking of an effect of "alveolation" for the spectator standing on the platform. It is a logical result of the laws of curvilinear perspective that all plane surfaces below the level of the eye must tend optically to "dish"; that is, to appear like a dish or bowl. Aeronauts find this appearance in the earth's surface when raised above it in a balloon, for the same optical reason. The same optical laws explain the dome-shaped appearance of the sky. Thus, although the explanation of Vitruvius is certainly insufficient to cover the known facts, it appears to be a common-sense and practical explanation, which deserves recognition and mention, among the many which have been offered. It is additionally interesting from the fact that it is not simply the outer porticos of the Parthenon which have the stylobate curves. The entire platform of the temple is delicately hemispherical; or, as the French would say, *bombé*.

photographs, taken under my direction, of the Temple of Concord at Girgenti, show that there are rising curves in elevation on the flanks (PLATE XVIII),[1] but no curves under the gable (PLATE XIX). Hence the curves of the flanks could not well be an afterthought derived from the curves under the gables, since the latter do not occur in this temple. This very important argument against the gable theory of Penrose has never been adequately published.

Penrose had based his argument for the derivation of curves on the flanks of a temple from the curves under the gable, on the high antiquity of the Temple of Poseidon at Paestum and on the supposed fact that this temple had curves under the gable, but none on the flanks. Thus, for Penrose, the Temple of Poseidon represented the primitive type of the Greek curves, but he was ignorant that Jacob Burckhardt in his "Cicerone" had announced constructive curves in plan convex to the exterior on the flanks of the Temple of Poseidon. These curves were photographed for the first time by the Brooklyn Museum surveys of 1895 (PLATE XX).

From the preceding summary two results are fairly well established. First, the popular impression that the Greek curves were intended to make the lines look straight, and to correct effects of sagging supposed to be inherent in straight lines above the eye, is without authority, so far as the quoted experts are concerned, and the theory of Burnouf, in the *Revue Générale de l'Architecture* for 1875, is too fanciful to require more than passing mention here.[2] The second result is this. So far as Penrose is concerned, he only suggested a sagging effect under the gables at the ends of a temple as the explanation of the curves. Against this theory the following points may be urged. It has not been accepted or favorably mentioned by any French or German expert. It has been vigorously opposed by two distinguished experts in optics, and the theory of Hoffer is also opposed to it in principle. It is finally thrown out of court by known facts in Egypt and at Girgenti.

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[1] Straight lines have been drawn on the negative, in order to show the rising curves in elevation of the stylobate and entablature.

[2] Even the briefest mention of Burnouf ought not, however, to omit to give him credit for having, alone among modern authors, given the correct explanation of the *scamilli impares* of Vitruvius. Penrose supposed that the *scamilli impares* were the drums of the columns which rested on the stylobate. These drums, in the Parthenon, are of unequal height on opposing sides. Otherwise the columns resting on the curved and sloping surface, would lean away from the centre of the temple. This interesting proof of the intended construction of the curves is not, however, the true explanation of the *scamilli impares*, by means of which the curves were to be constructed. Even in the second edition of his *Principles of Athenian Architecture*, published in 1888, Penrose was still ignorant of the obviously correct explanation offered by Burnouf in 1875. It is significant of the general neglect by archaeologists of the subject of

We are now able to return to the discovery of Professor Giovannoni at Cori, which disposes of the gable theory of Penrose for all time, as a general or universal explanation of the classic curves, for the simple reason that the curve at Cori produces a sagging effect in the upper horizontal line and therefore could not counteract one.

But the discovery does far more than this; it forces a revision of most of the other theories on Greek curves and widens our views regarding them to a very remarkable extent. And before I take up this phase of the subject I wish to point out the possibility that the curves at Cori may not be the only ones which are concave to the exterior, even in existing classic monuments.

Pennethorne observed curves *in plan* concave to the exterior in the entablatures at the ends of the Parthenon. Hoffer explicitly described the same curves and measured them. The plan of these concave curves, with measurements, is published in the *Wiener Bauzeitung* of 1838. Hoffer described these curves in plan as beginning in the capitals, as continuing in the entablature and sloping cornice, but as not being found in the face of the tympanum. They amount to about two inches only, at the cornice. Penrose quotes the observation of Pennethorne

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Greek curves that Burnouf's explanation has not even been alluded to by any other authority.

Burnouf points out that *scamillus* is a diminutive of σκάμνον, and may be translated as "a little stool" (Burnouf says *un petit banc*). These little stools were the small pyramid-shaped sighting blocks which are still used in France for levelling a line of steps or a masonry platform. If placed in graded unequal sizes, gradually increasing in height from the centre toward the extremities of the line of steps, such *scamilli* could be used for constructing a curve, and, as Burnouf says, it was as easy in antiquity to construct a curve with these implements, as it now is to build to a level. He also points out that such *scamilli impares* must have been used for building curves in plan.

and gives his reasons for believing the curves to be accidental. In deference to Penrose, Pennethorne, in 1878, adopted his view that these curves were accidental. The argument of Penrose is that the gaps between joints were greater in the rear than in the front. Hoffer's observation that the tympanum surface is without curve would appear to suggest that the curves above and below it could hardly be due to accidental movement. No decision on such a head can be reached, or even suggested, in this paper, and the explosion which ruined the Parthenon is not to be forgotten, but it is surely worth remembering, in face of the concave curves at Cori, that concave curves in the Parthenon gable fronts were observed, measured, and published in 1838, by Hoffer, as constructive.

There is another observation on this head which is attested by the photograph herewith published. In 1895, I observed curves in plan concave to the exterior in the eastern pediment of the Temple of Poseidon at Paestum, and they were photographed at that time. This photograph (PLATE XXI) shows the concave curve in the line of abaci as well as in the cornice. I have never previously published these facts, for lack of time and opportunity, but I was moved by the observation at Cori to make them known to Professor Giovannoni and to send him a photograph. This observation has been laid before the Roman Society by Professor Giovannoni at their session of November 6, 1906, and the President of the Society has been kind enough to write me a congratulatory letter on this subject. It appears to me of high importance that the curve in plan at Paestum, concave to the exterior, should be carefully examined by experts, on the site. Whatever the result at Paestum might be, the curves at Cori still remain the first conclusively demonstrated constructive curves in plan, concave to the exterior, which have ever been found in a classic monument.

This is the proper point at which to close this paper, for it is not my purpose to explain these concave curves. So long as it appears certain that the facts now known are sufficient to compel new explanations it seems hardly worth while to figure as a theorizer. It is mainly my wish to show that previous explanations of the classic curves are insufficient to cover the facts now known. I may, however, add that Professor Giovannoni's announcement of the curves at Cori was made to the Roman Society of Architects in a report of a favorable nature regarding my own observations of mediaeval asymmetries and deflections. Therefore, I may also add that the closest mediaeval analogy to the façade at Cori is that offered by the lower façade of St. Mark's at Venice, which curves concave to the exterior, from the foundations up, with a deflection of 10 inches at the foundations (PLATE XXII).[1]

It appears highly improbable that the façade of St. Mark's was curved for the effects of concavity in the upper line.[2] It is rather probable that the entire surface of the façade was considered. As regards line effects the curves would, below the level of the eye, produce the optical effect of rising curves in vertical planes. Above the level of the eye they would produce the optical effect of descending curves in vertical planes. These line effects are optically contradictory and therefore optically illusive. They must, therefore, give to the façade an effect of "life" or of optical mystery and vibration.

As regards views slanting along the façade of St. Mark's from left to right, or *vice versa*, the perspective effect is enhanced very considerably in the way of magnitude, if the terminal upright lines, rather than the upper horizontal lines, be considered. But here again it appears more likely that an effect of optical mystery and vibration, rather than a direct increase of size in perspective, was considered. It may be that the delicately varied effects of light and shadow, which are involved in a curved surface, were the dominant consideration.

As regards the façade of St. Mark's, it should be remembered that only the lower façade is in question, and not the upper façade, which stands back of a wide platform, bounded by the cornice of the lower façade. Although this cornice has not been levelled or plumbed, it appears to rise from the extremities toward the centre so as to correct the effect of concavity at the cornice line. (In the upper façade the pinnacles are arranged in descending heights from the centre toward the extremities.)

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[1] The deflection is best seen on the outer line of the paving slabs in front of the church.

[2] And especially so for the reason mentioned later, that the cornice line appears to the eye to be built with slight obliquities rising from each end toward the centre, so as to correct the effect of concavity.

In simple language, and aside from optical explanations, the façade of St. Mark's, in my opinion, gains vastly in artistic charm by its delicately and imperceptibly curvilinear surface, as well as by its subtle variations in the dimensions of the arcades. If mediaeval curves be admitted to have been constructed at all, it must be conceded that the lively effect of the curved line or surface was held to be superior to the rigidity and greater formalism of the straight or plane surface, and that no other universal explanation can be offered. Whether or no this lively effect is physiologically due to optical mystery, which is again due to an optical vibration between the contradictory optical effects which must always be found in delicately distorted architectural surfaces or lines, or whether it is due to varied effects of shadow, is hardly worth debating. It may be that both explanations have to be considered. I offer the suggestions for what they are worth, with the remark that the concave curve in plan at Cori demands some kind of explanation.

If mediaeval analogies be excluded, it is still evident that some explanation similar to those which have just been offered for them must now be sought for such ancient curves as are found at Cori. This involves farther reference to the concave curves in the Parthenon, if for no other reason than the one that other experts than Hoffer have already been inclined to admit their constructive existence. Thus Reber[1] considers the concave curves of the Parthenon to be constructive. His explanation is significant in view of the fact that the optical effect, in front view, is that of a descending curve in a vertical plane, which equals the amount of the curve in plan at the angle of 45 degrees, which decreases in amount from farther points of view, and which increases in amount on nearer approach. Reber holds that the concave curve was intended to contradict and decrease the excessive curve in elevation due to the combination of the optical perspective effect in elevation, on close approach, with the constructive curve in elevation. The interesting feature of this explanation (although it cannot be applied to Cori) is that it realizes the two effects as being contradictory. Hauck quotes the explanation of Reber with tentative approval[1] and expressly affirms the principle that the effects of a rising curve in elevation and of a concave curve in plan are contradictory, and that the optical effect of the concave curve is that of a descending curve in a vertical plane. It is, of course, understood, as Hauck points out, that the contradictory effect is insignificant from distant points, and then almost disappears.[2] It is also understood that whereas the rising curve in elevation has its greatest relative effect from a distance, the optical perspective curve is far the greater on close approach, so much so, that on close approach the constructed curve in elevation is not an important addition to its amount. Neither Reber nor Hauck has considered the possibility that the concave curve might have been considered desirable for its effects from the slanting side view, and Hoffer is at a loss for any explanation.

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[1] *Kunstgeschichte des Alterthums*, p. 207.

Although the constructive facts in the Parthenon may be held to be doubtful, the above explanations are of value as showing the difficulties which have hitherto surrounded the explanations of concave curves in plan, and also as showing that the effects of concave curves in plan above the level of the eye are recognized by optical experts as being those of descending curves in elevation for the front view.

The concave curves at Paestum do not appear to be exposed to suspicion on the score of constructive existence, and here again there are also rising curves in elevation at each end of the temple.

For the Temple of Cori the question is not complicated by the existence of curves with contradictory effects, but it still remains to be debated whether the side effect was not considered as much as the front view. The Temple of Cori stands on a high elevation, and the front view from below would, on near approach, much increase the optically descending effect toward the centre of the curve. For such points of view it could only be presumed that the curve was considered more agreeable than the straight line, without reference to the question whether it was a rising or a descending curve. For the side view the effects would be optically contradictory as regards perspective, an effect of increase if the vertical terminal lines be considered, and an effect of decrease if the upper horizontal lines be considered.

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[1] *Op. cit.*, pp. 109, 144.

[2] It would disappear entirely when the eye is on the level of the concave curve. Here the concave curve appears as a straight line.

It is a natural result of our interest in the surviving ancient monuments, that we tend to overlook their actually very small number and the enormous number of those which have utterly disappeared. The discovery at Cori makes it probable that curves were employed in ancient art to a much greater extent and in much greater variety than has hitherto been supposed. The same conclusion would inevitably be suggested by the possibility that the mediaeval curves are historically related to the classic ; because the mediaeval curves exhibit a variety of character and use far surpassing that which has been hitherto presumed to exist in antiquity.

In a paper which I published in this JOURNAL, Vol. VI, 1902, pp. 166 ff., 'Architectural Refinements in Italian Churches,' I discussed the optical effects of the cloister curves, convex to the centre of the court, at Verona and Bologna. I pointed out that the line effects were contradictory above and below the level of the eye inside the corridors, and that they were again contradictory, but in the reverse sense, as observed on the exterior, *i.e.* from the interior of the court. From this I argued that the curve must have been preferred for its own sake and independent of any definite particular perspective effect. It has since occurred to me that an effect of vibration or of optical mystery in such curved lines or surfaces, must result from the shifting of the eye to different lines or planes of sight or from the inclusion, at points more distant from the eye, of such contradictory effects within the limits of fixed vision in a single direction. In churches like S. Apollinare Nuovo at Ravenna, which have true parallel curves in plan in the alignment of columns, continuing in the walls of the clerestory, it is evident that the optical effects must again be contradictory on the two sides of the nave, because the columns and wall surfaces are concave to the nave on one side and convex on the other.

In the Pisa Cathedral, moreover, where the gallery parapets are built in parallel curves in plan (which continue in the walls above) the same parapets also have constructive rising bends in elevation (*Arch. Rec.* VI, No. 4).

Thus, from the pavement below, the curve in plan increases the effect of the bend in elevation on the south side, where it is convex to the nave, and decreases it on the north side, where it is concave to the nave. (For the north side of the nave, the facts are analogous to those in the Temple of Poseidon at Paestum, and in the Parthenon, where contradictory effects are found in the cornice.) It may also be pointed out that, wholly aside from curves, I have always contended that effects of optical mystery were studied at Pisa. The explanation is offered for what it is worth, and any others would be equally satisfactory to me which cover all the constructive facts.

Finally, as regards relationship in feeling, if not in continuity of historic practice, as between Antiquity and the Byzantine and Romanesque monuments of Italy, the authority of Jacob Burckhardt may be cited. Ernst Foerster, in his *Handbuch für Reisende in Italien*, I, pp. 364–365, was apparently the first to announce intentional irregularities of line in the Pisa Cathedral. He held them to be "die unbeholfensten Aeusserungen des romantischen Kunstgeistes." Jacob Burckhardt's footnote to the account of the Leaning Tower in his "Cicerone" quotes Foerster's idea as follows:[1]

"For the history of art Foerster's opinion about the relation of the Leaning Tower to the irregularities of measurement, oblique and bent lines, irregular intervals, etc., would be much more important [than his opinion about the Tower itself]; in all these things he sees a dislike of mathematical regularity and of exact symmetry; these are said to be 'the clumsy expression of Romanesque endeavor' (Die unbeholfensten Aeusserungen romantischer Bestrebungen). *Since we must unconditionally admit something of the kind in Greek temples, this view has something very attractive.* I believe, however, that the given phenomena must be otherwise explained, and, namely, not by want of dexterity,—which could not be suggested for the noble Pisan buildings,—but by an indifference to mathematical accuracy, which was peculiar to the earlier Middle Age."

Burckhardt then proceeds to give examples of this indifference (which certainly also existed). The footnote just quoted inspired me to make a personal call on Jacob Burckhardt at Basel in 1870. I showed him the measurements and drawings which I had just brought from Pisa. He advised immediate publication, and professed his previous ignorance of the facts thus brought to his notice. Thus my own contact with Burckhardt showed that he was not familiar with the constructive facts at Pisa, whereas to him belongs the original suggestion that, if the constructive facts exist, they would be analogous in feeling to the deflections and asymmetries of Greek temples. (Burckhardt's matter on the Temple of Poseidon at Paestum to which he refers in this footnote has been retained in later editions.) To Foerster, on the other hand, belongs the original suggestion that obliquities and bends were intentionally constructed at Pisa. He can hardly, however, have noted the true and delicate curves which are also found in the cathedral, for these certainly cannot be called "unbeholfen" or clumsy.

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[1] This footnote appears only in the first three editions.

As a final suggestion for façades like those of St. Mark's and Cori it appears that the varying effects of light and shadow may have been the important consideration. Since these varying effects of light and shadow were notoriously studied with the greatest care in the profiles of classic architecture, why may they not have been considered for the surface of the façade at Cori? The same explanation may be sufficient for the concave curves of Paestum and of the Parthenon.

WILLIAM H. GOODYEAR.